LARP Conductor and Cable R&D

D.R. Dietderich, LBNL

June 17-18, 2004

Objective

- Map parameter space for fully-keystoned cables with present strand (Oxfords RRP)
  - And others (PIT & IT) as they become available

- Develop a LARP strand specification
  - Leverage Conductor Development Program of HEP

Outline of Presentation

- Cabling Needs
  - R&D effort to develop reference or baseline cables
    - Narrow cables for 4 layer cosine 2θ quad
    - Wide cables for 2 layer cosine 2θ quad, (useful for cosine θ dipole)
  - Cable measurements
    - Ic of cables
    - Effect of stress on Ic
- Strand Needs
  - Target strand specifications
  - R&D effort
    - Jc, RRR, M, D_{eff}, strand stability
- Strand procurement
  - Strand specifications
- Radiation hard materials

Tasks and Objectives – Cable R&D

Near Term

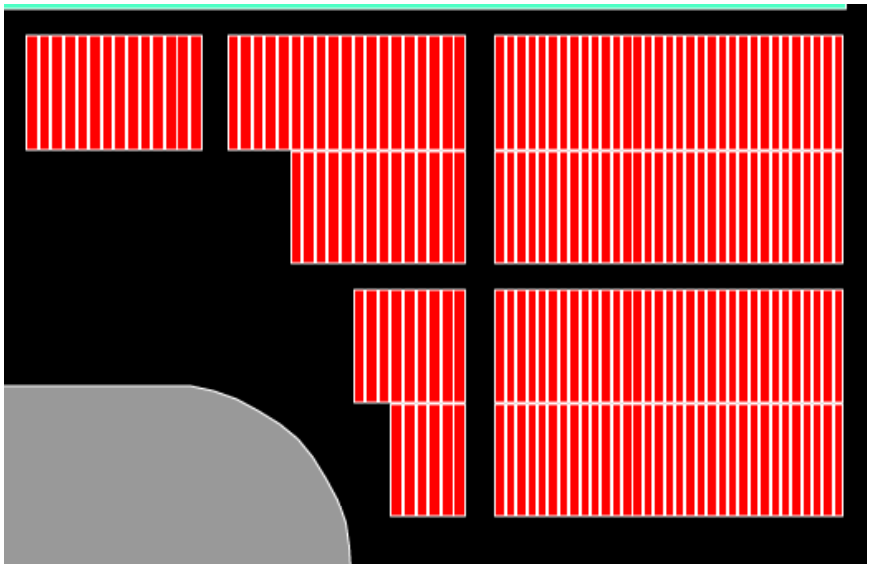
- Establish cable parameters for cable of 4-layer design
  - Extend LBNL's rectangular cable used for sub-size coils
    - 20 Strands and 0.7mm diameter

Longer Term

- Fully keystoned cables for 2-layer designs
  - Core near thick edge of cable
    - Reduces strand deformation & improves mechanical stability
  - Explore the use of Cu-SS core

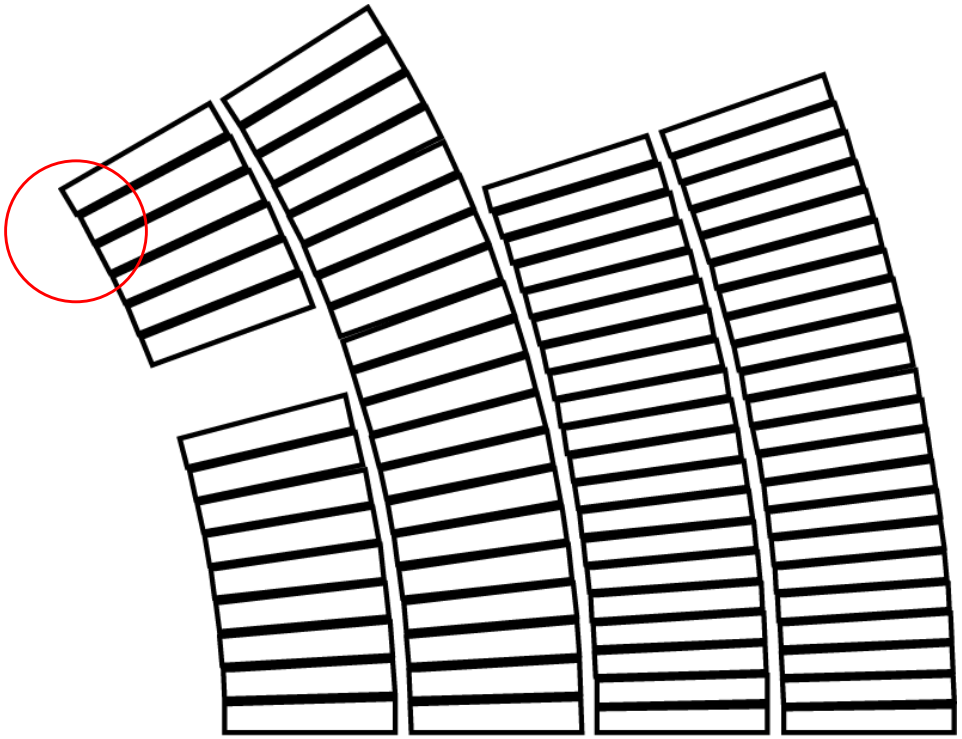
Cable R&D: Block Coil Magnets

- Rectangular Cable
  - applies to race track dipole and quad
- Experience from RD-3, HD-1 and sub-scale magnets
  - No damaged strands during cabling (i.e. no reduction in Ic)
  - Mechanically stable for coil winding
  - Not much R&D
    - Except for new strands



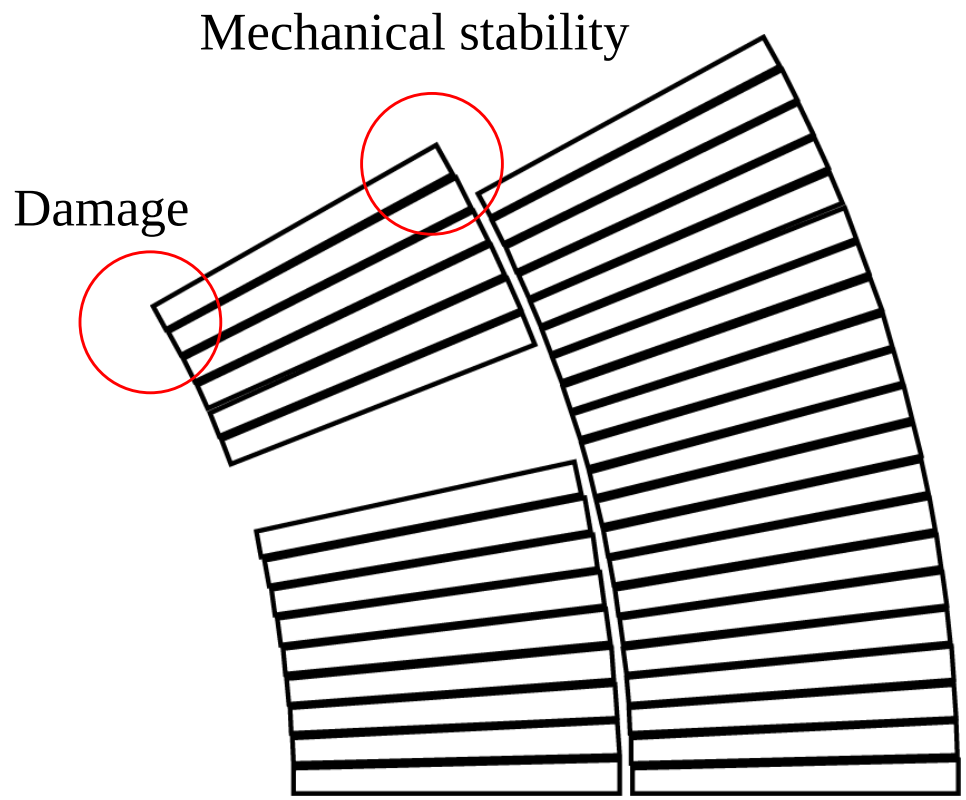
Cable R&D: 4-layer Magnets

- Fully Keystoned cable
- Sub-scale as reference
  - 20 strands, 0.7mm
  - Determine cabling limits
    - Damage at thin edge
    - Should be mechanically stable



Cable R&D: 2-layer Cosine 2θ Quads

- Fully Keystoned cable
- Twice the width of 4-layer design
  - Greater risk of damage at thin edge
  - Greater risk of being mechanically unstable



Proposed Cosine 2Θ Quad: LBNL

Parameter	Unit	2-layer	4-layer	
			Inner	Outer
Strand diameter	mm	**0.7**	**0.8**	**0.65**
Cu/Sc ratio		1.5	1.2	1.6
No. strands		**42**	**17**	**22**
Cable width	mm	**15.8**	**7.7**	**7.7**
Cable mid-thickness	mm	1.45	1.43	1.13
Keystone angle	deg	**1.38**	**1.63**	**0.89**
Insulation thickness	mm	0.1	0.1	0.1
No. turns/octant		36	35	42

G. Sabbi

Proposed Cosine 2Θ Quad: FNAL

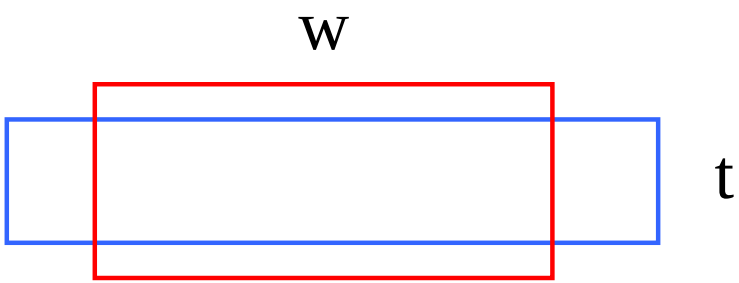
Parameter	Aperture				
	110 mm		100 mm		90 mm
Coil layers	outer	inner	outer	inner	both
Number of strands	24	18	18	14	42
Strand Ø, mm	1.0				0.7
Cable width, mm	12.33	9.23	9.23	7.17	15.14
Inner edge, mm	1.59	1.66	1.61	1.67	1.08
Outer edge, mm	1.94	1.87	1.92	1.86	1.39
Keystone angle, deg	1.7	1.3	1.9	1.5	1.18
Aspect ratio	7	5	5	4	12

V. Kashikhin,
FNAL

Cable Fabrication

Need to decouple thickness
& width deformations

Problem with Area Compaction



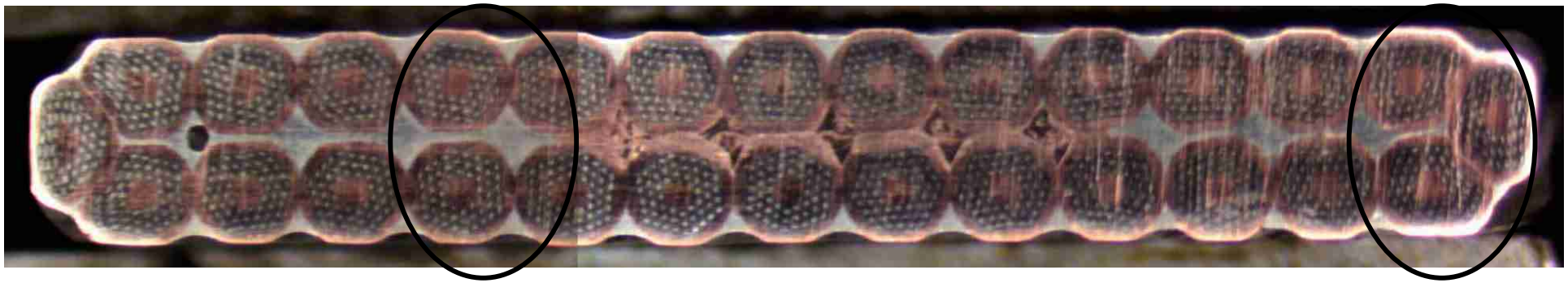
2 Cables: Same compaction

16.4 mm x 1.400 mm = 22.96 mm2	
16.0 mm x **1.435** mm = 22.96 mm2	

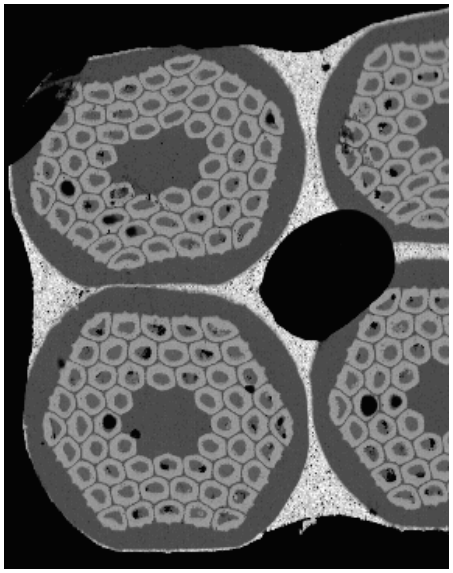
0.4mm
Half a strand diameter

0.8 mm strand diameter
40 Strands
Area of strands = 20.11 mm^2
87.57% Compaction

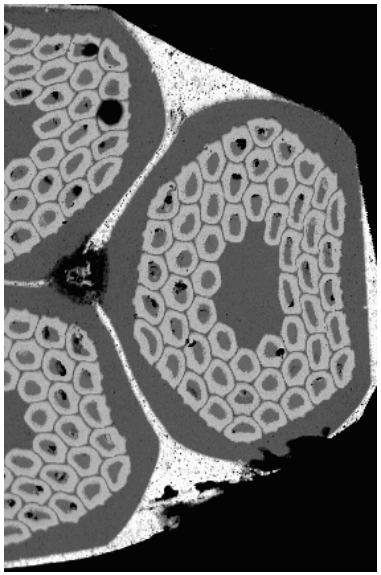
Rutherford Cable



Middle of cable

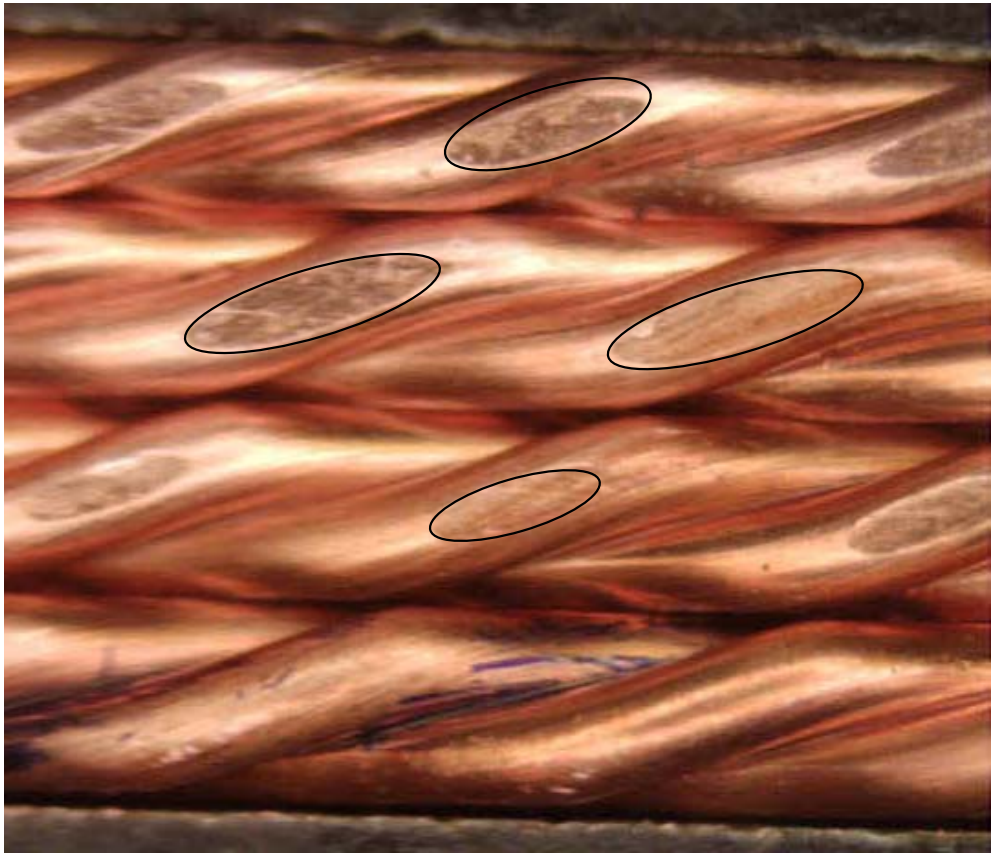


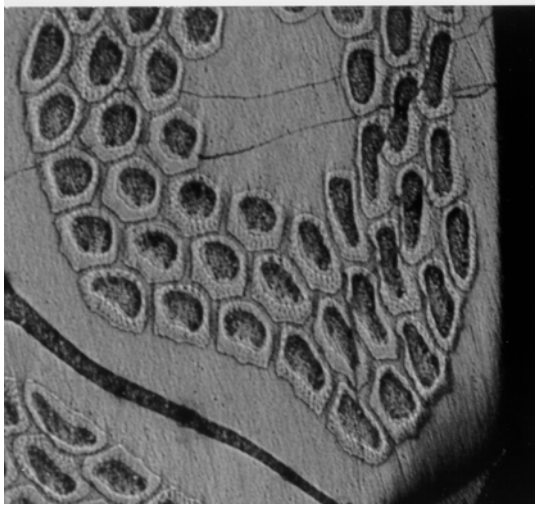
Edge of cable

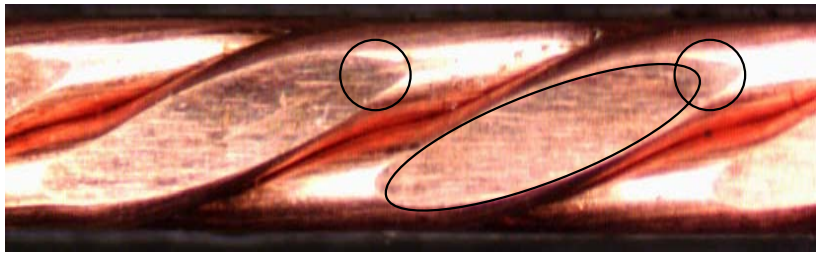


Quantify Cable Deformation

- Area of edge facet



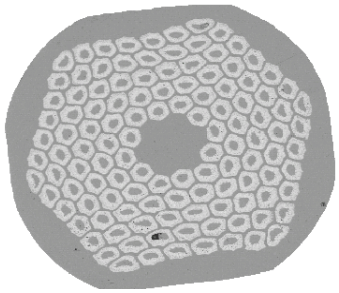




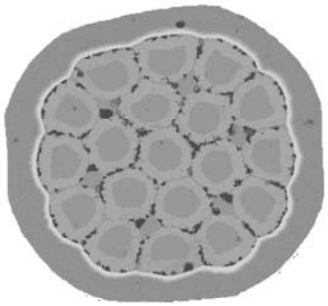
- Large facets: deformation too high
- Potential for real time monitoring

Cables history at LBNL: D-20, RD-3, and HD-1

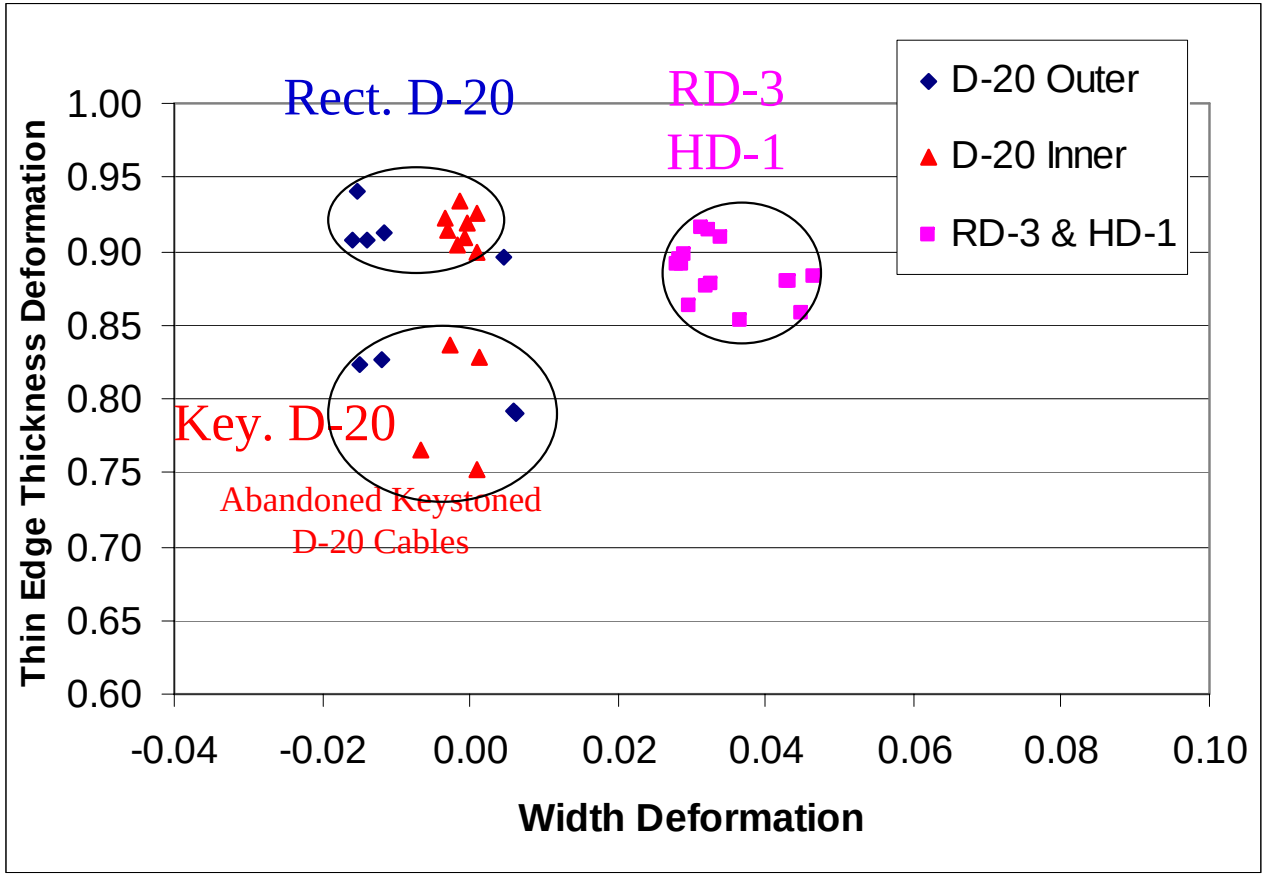
D-20



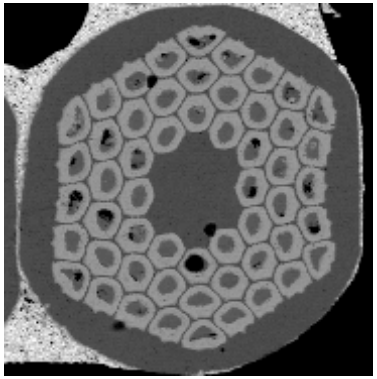
LBL Cable # 523
MJR-TWCA



LBL Cable # 522
IGC-Int. Tin

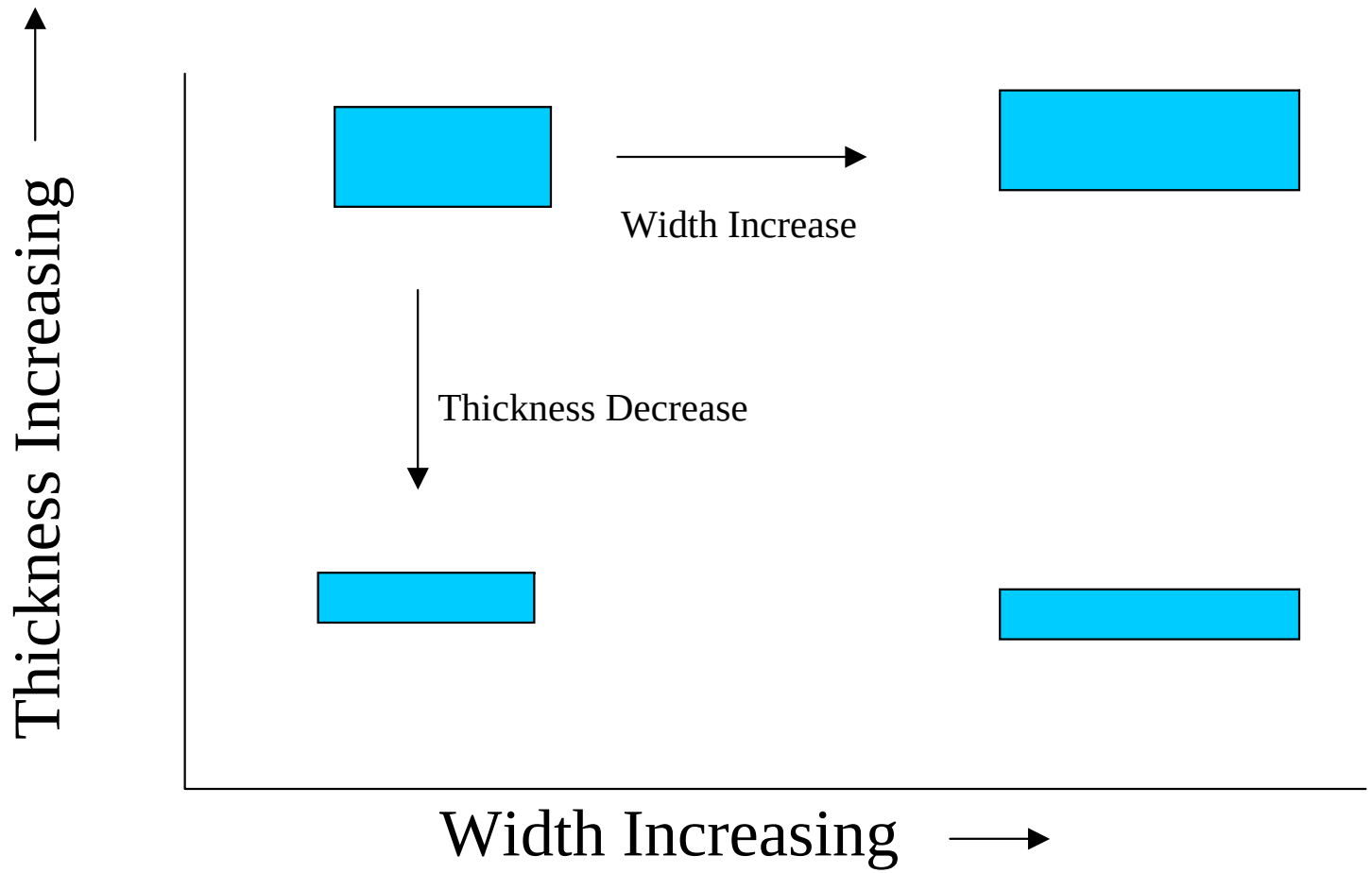


RD-3



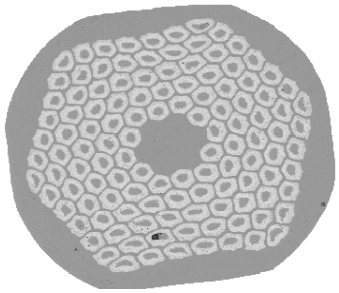
LBL Cable # 805R
Oxford-ORe

Cable Parameter Space

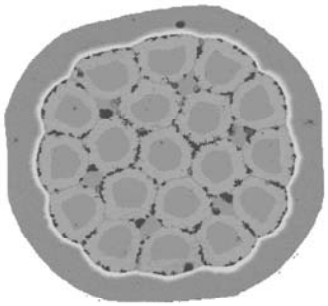


Cables for D-20, RD-3, and HD-1

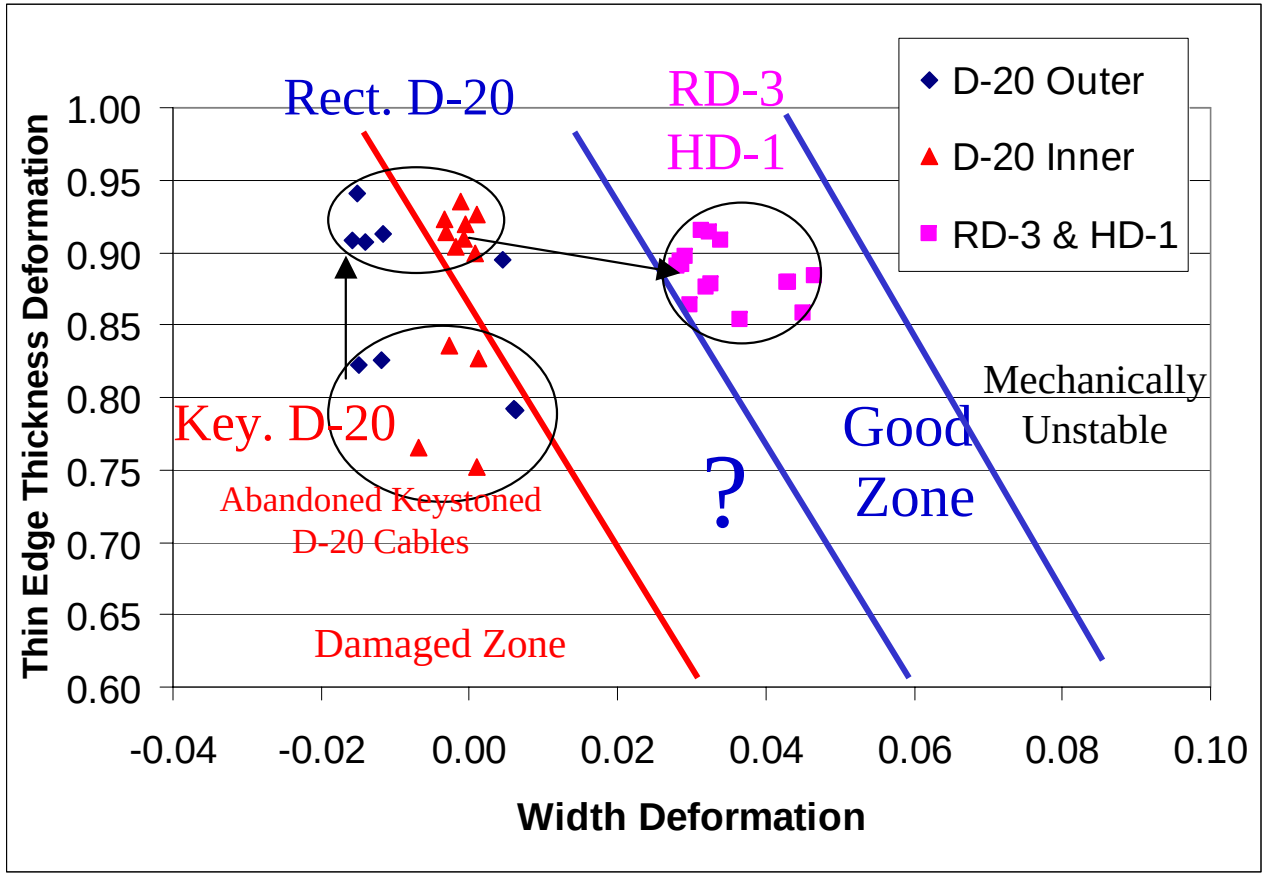
D-20



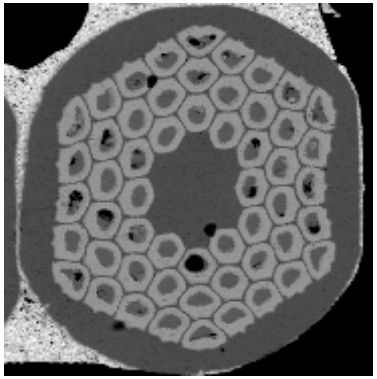
LBL Cable # 523
MJR-TWCA



LBL Cable # 522
IGC-Int. Tin

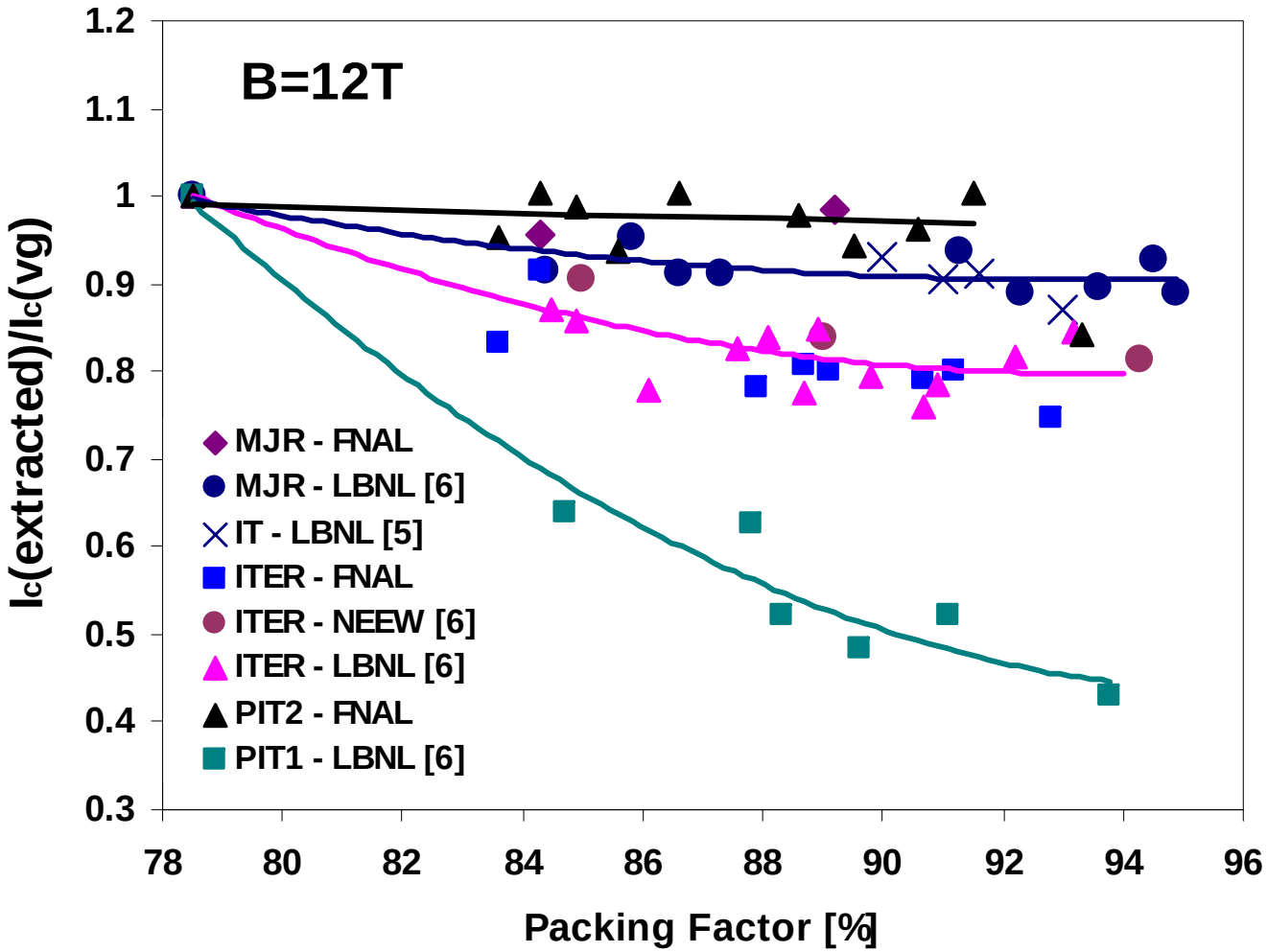


RD-3



LBL Cable # 805R
Oxford-ORe

Critical Current Reduction of Strands Extracted from Cabling

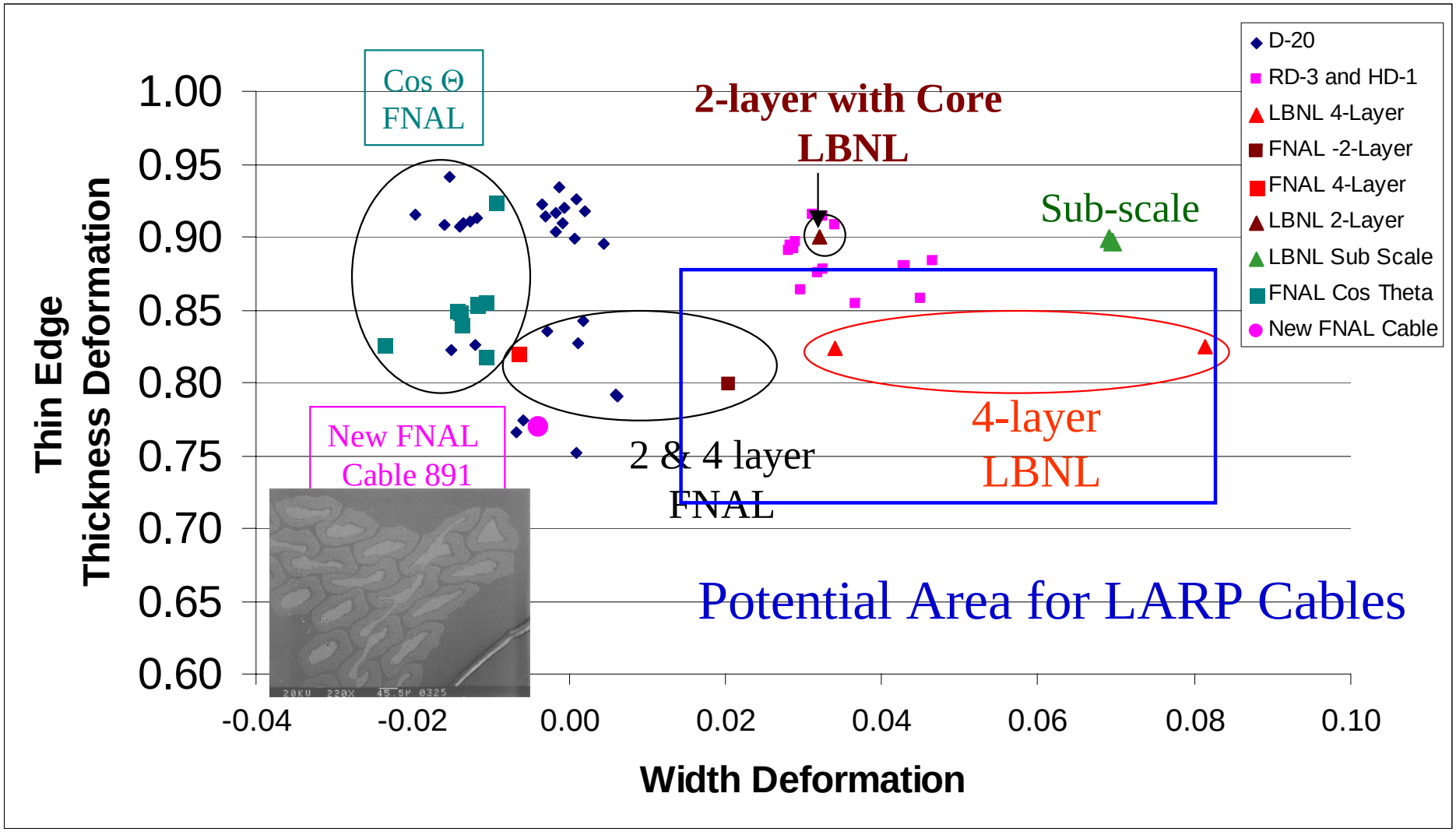


E. Barzi, FNAL

Critical Current Measurements of Cables

- Sub-scale race track coils
  - Develop winding and assembly method for keystoned cables
- BNL
  - 7T dipole, 25,000A
  - 4 layer quad cable
- CERN (FRESCA)
  - 10T, 32,000-40,000A
  - 2 layer quad cable
- NHMFL
  - 12T split pair solenoid, 20,000A
  - 4 layer quad cable
- FNAL
  - 28,000A superconducting transformer, 1 cable/day, self-field

Fully Keystoned Cables for LARP

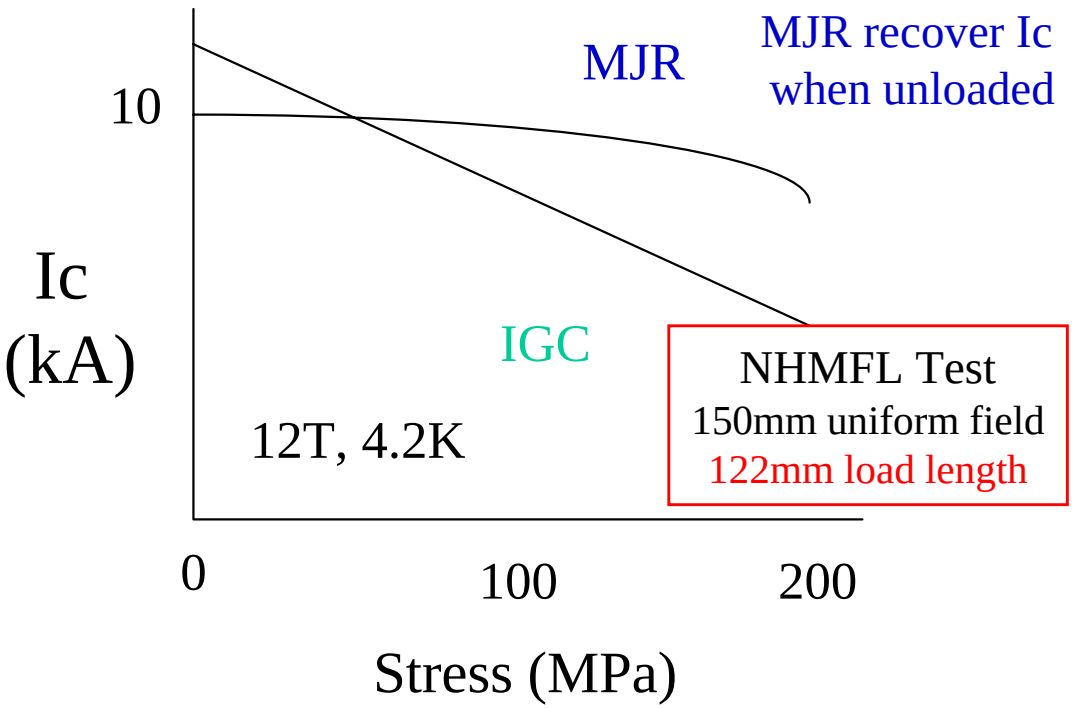


Cable R&D : Modify Strand Mechanical Behavior

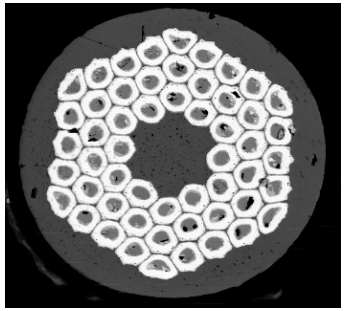
- Present Nb_3Sn cabling procedure at LBNL (Coils for RD-3b, RD-3c, HD-1)
  1. Fabricate cable
     1. Slightly over size
  2. Anneal at 210°C/6h
     1. Softens Cu and cable contracts by ~0.25% in length
     2. May harden Sn core
  3. Re-roll to decrease thickness by 25-50 μm.
     1. Compacts cable making it mechanically stable
- Plan to flow for LARP
  - May try increasing annealing temperature and time

Sensitivity of Strand to Transverse Stress

- Stress not an issues?
  - New RRP comparison to D-20 MJR?
  - Less Cu more Nb_3Sn inside sub-element
    - **Nb_3Sn filaments sinter**

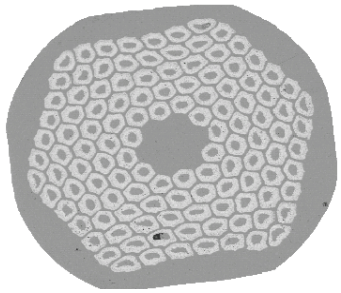


HD-1



RRP-Oxford

D-20



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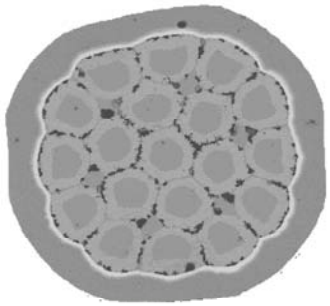
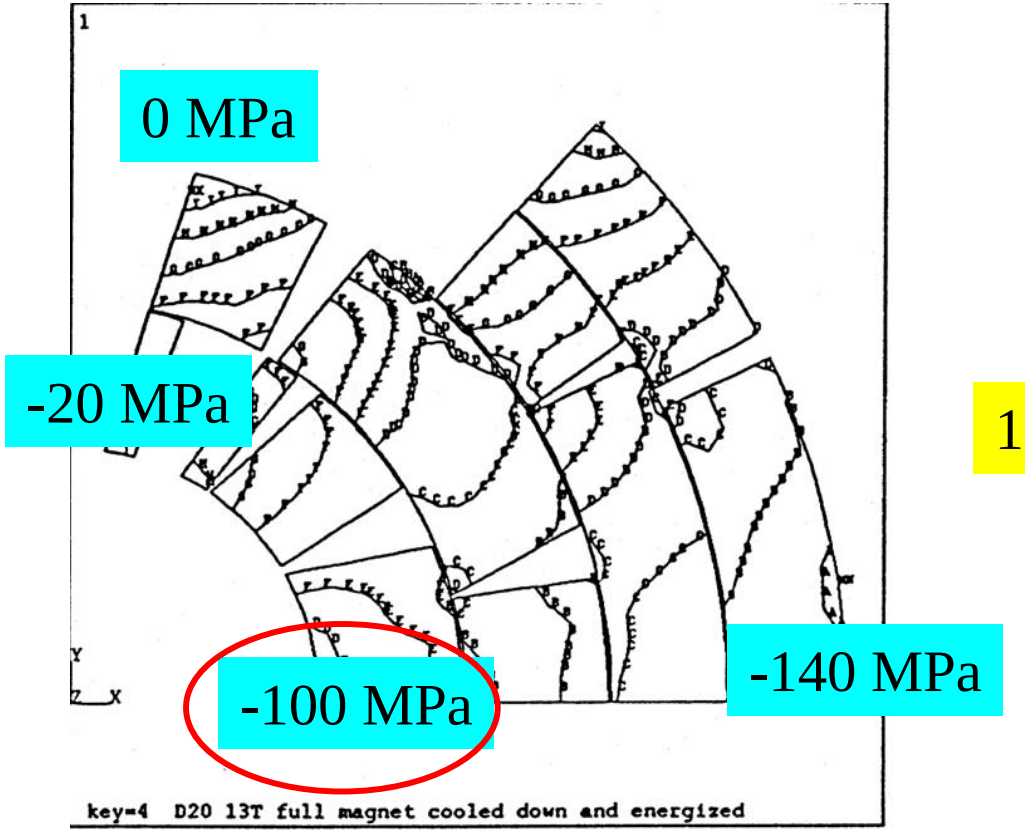
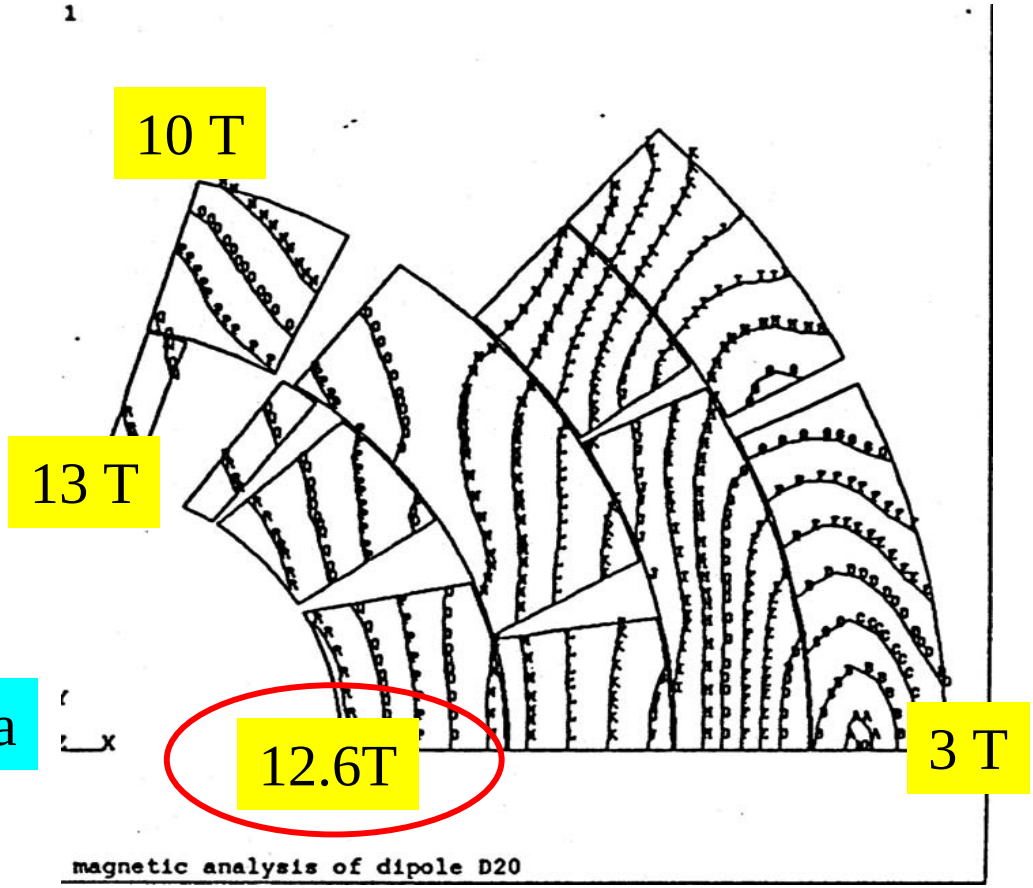


LBL Cable # 522
IGC-Int. Tin

D-20 Azimuthal Stress and Magnetic Field in Coils at 13T Peak

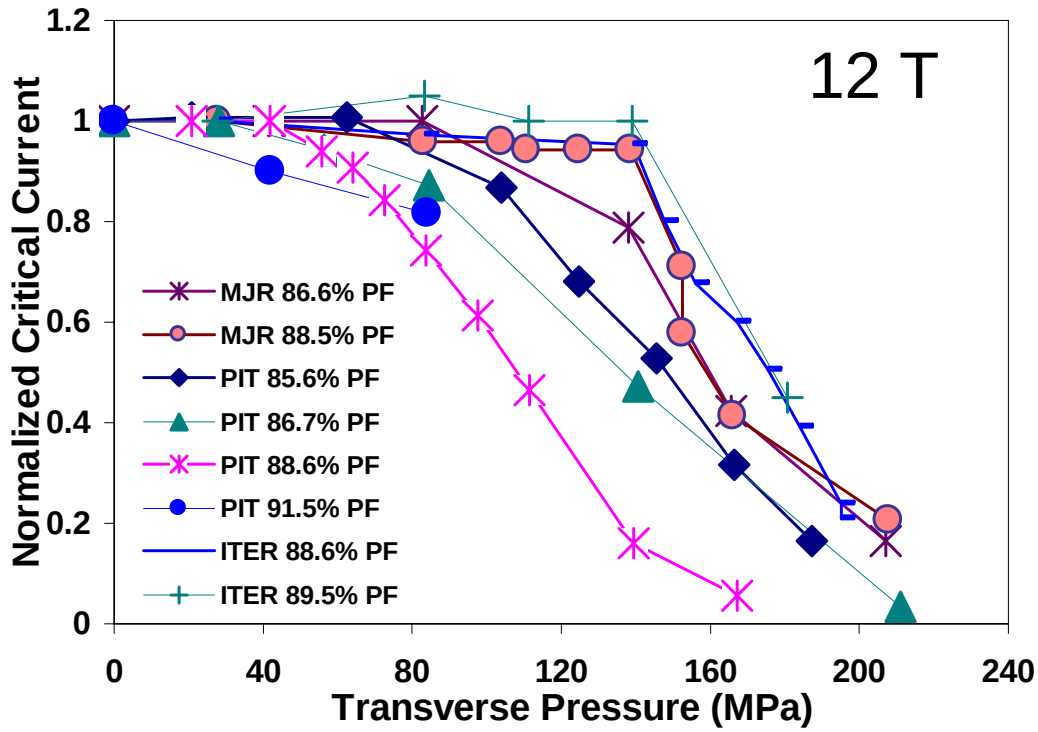




The **narrow edge** of a keystoned cable is located at high field and high stress point

Transverse Pressure Measurements

- Single superconducting strand in cable of Cu wires
- Correlate to prototype magnet performance to determine if stress limiting
- Need to measure more cables under transverse pressure



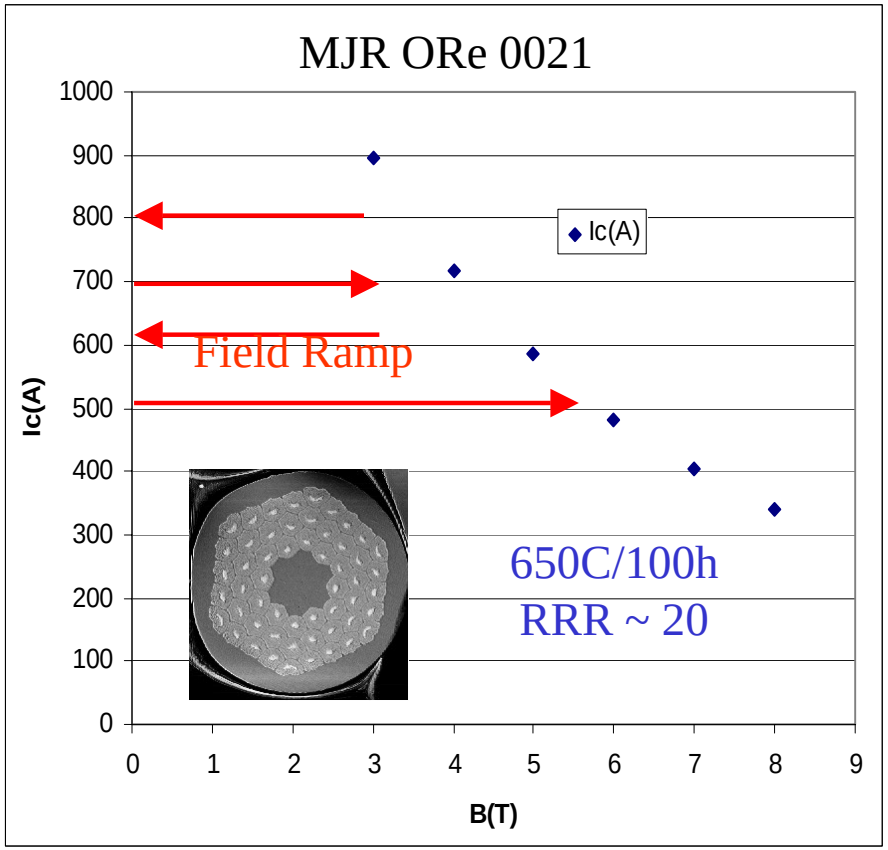
E. Barzi, FNAL

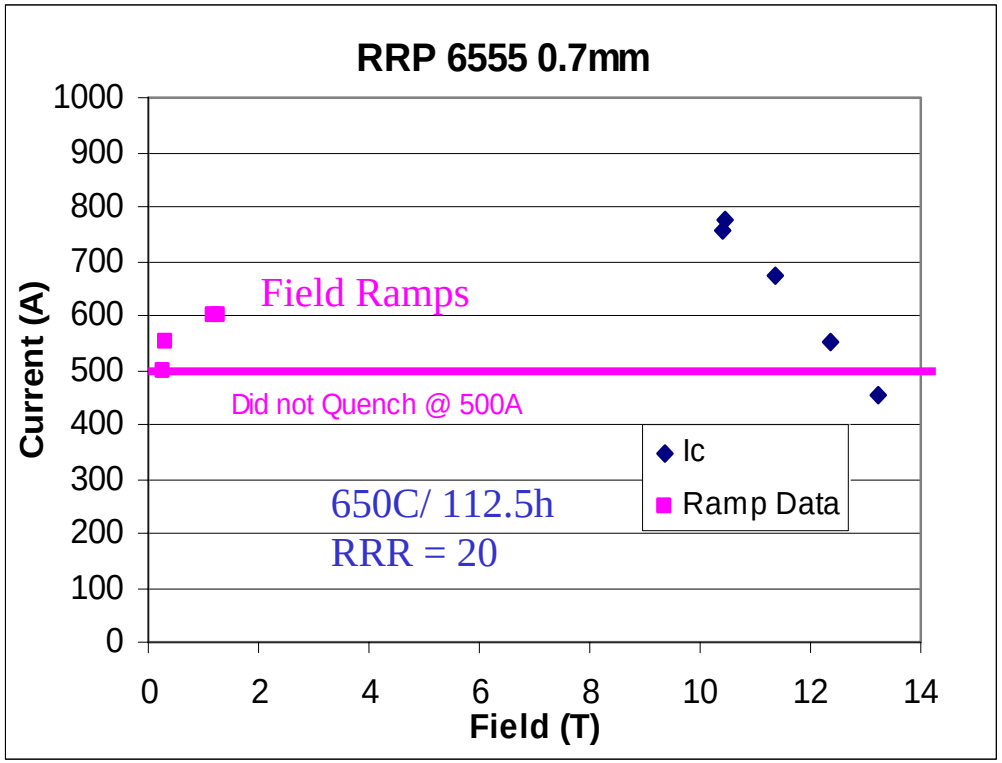
Strand Requirements

- Strand Short Term (1-2 years)
  - Strand diameter 0.7mm
  - 50-60% Cu
  - D_{eff} (90-120μm)
  - Strand instability (Base programs)
  - Stress not an issue?

- Strand Long Term (> 2 years)
  - Strand diameter 0.65-1.0 mm
  - D_{eff} (50 μm) Is this small enough?
  - Strand instability (Rresolved?)
  - Stress?

Strand Stability





Diameter = 0.48mm
Sub-element ~ 60 microns

Diameter = 0.7mm
Sub-element ~ 90 microns

Responsibilities

- D. R. Dietderich (LBNL) -- Cabling
- E. Barzi (FNAL) -- Strand Characterization
- A. Ghosh (BNL) -- Cable testing (4-layer)
- G. Ambrosio (FNAL) -- Cable testing (2-layer)

Radiation Hard Materials

- Long term need (>3 years)
  - Potting compound is going to limit magnet life
  - Keep abreast of the improvements in epoxies
    - EX-1515 (JPL/NASA)
    - CTD-422 Cyanate Ester (CTD/Atomic Institute in Vienna)
    - Matrimid 5292 (FNAL)
  - Magnet fabrication processes need to be compatable with new materials
    - Short prototypes
    - Long magnets

D. Chichili, FNAL
Erice

Cable -- Priorities and Plans

- Cable R&D
  - Deformation limits of existing strand
    - Oxford Strand -- Restack Rod Process (RRP)
      - RRP 54 sub-element ---- 120 sub-element
      - HER
    - Outokumpu
      - Internal tin
    - SMI and Supercon, Inc.
      - Powder in tube (PIT)
  - Keystone cables
      - Keystone angle (strain limit): Usually a issue at thin edge
      - Mechanical Instability (winding issue): Issue at thick edge
        - » Both of these issues less of a problem with NbTi

Summary

- Within 3 years map the parameter space for damage free and mechanically stable cables needed for LARP with all of the strands available.

- Within 3 years have a strand specification that provides a high J_c and RRR, and a small D_{eff} that is stable for all field ranges.